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DEVELOPMENT OF DISTURBANCES IN SWEPT WING FLOWS

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DEVELOPMENT OF DISTRUBANCES IN SWEPT WING FLOWS

By

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I. INCOMPRESSIBLE TWO-DIMENSIONAL BOUNDARY LAYERS WITH PRESSURE GRADIENTS AND SUCTION

Three dimensionality is known to be a necessary prerequisite for transition. A key three-dimensional phenomenon in the early stages of transition is characterized by a strong secondary instability of 3D disturbances in the presence of finite amplitude two-dimensional primary disturbances. This secondary instability has been recognized experimentally and observed numerically in boundary layers. Several routes to transition have been identified. One route is characterized by subharmonic 3D disturbances that are excited in the boundary layer at very low level of the TS amplitude. This mechanism produces either the resonant wave interaction predicted by Craik (C-type), or the secondary instability of Herbert (H-type). The other route, the so-called K-type (peak-valley splitting), occurs as the TS amplitude exceeds a certain threshold value.

Research Objective

We are concerned with the subharmonic secondary instability mechanism as a route to transition that seems to be most dangerous in low-disturbance environments, as they are found in free flight. We investigate the development of a subharmonic secondary instability in a boundary layer with pressure gradients controlled by suction. Our objective is to evaluate the effect of suction control on this early stage leading to transition.

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Accomplishment Description

The calculations showed that stabilization of the boundary layer by active means (suction) or by passive means (modifying pressure gradients) or by a combination is a very sensitive process. While weak suction rates produce strong stabilizing effect on the subharmonic secondary instability (decrease growth rates, and amplification factors and limit the band of dangerous spanwise wavenumbers), weak unfavorable pressure gradients produce strong destabilizing effect on the subharmonic secondary instability.

The onset of the subharmonic secondary instability requires that the primary amplitude exeeds a threshold value. This value is Reynolds number dependent, it decreases as Reynolds number increases.

For laminar flow control suction should be applied near the onset of the primary instability to control the evolution of the primary amplitude and not near the onset of the secondary instability.

Publications and Presentations

1. "Effect of suction on the secondary instability of boundary layers," by N. M. El-Hady, Bulletin of the American Physical Society, Vol. 32, No. 10, 1987. Presented at the 40th Annual Meeting of the Division of Fluid Dynamics, held in Eugene, Oregon, November 22-24, 1987.
2. "Secondary subharmonic instability of boundary layers with pressure gradients and suction," by N. M. El-Hady, NASA-CR 4112, also submitted to Phys. Fluids.

Future Plans

Recent progress in understanding secondary instabilities may prompt modification to transition prediction schemes to rely on a secondary instability theory. A modified e^n criterion can be reached that involve the

amplitude of the primary disturbance or a measure of the background disturbance. This work is under progress.

II. COMPRESSIBLE TWO-DIMENSIONAL BOUNDARY LAYERS

Theoretically or experimentally, the compressible stability theory lacks a firm connection with boundary-layer transition. There is little doubt that transition is preceded by linear instability in many instances, but the way these individual unstable waves act, alone or in combination, to trigger the transition process is not known. The nonlinear theories and the secondary instability that are much a prominent feature of incompressible stability theory do not exist for compressible boundary layer.

Research Objectives

We formulated the secondary three-dimensional instability problem for compressible boundary layers to investigate theoretically the effect of finite amplitude two-dimensional wave on the growth of three-dimensional perturbations in compressible boundary layers. We cover only a range of Mach numbers up to the transonic, where the critical primary disturbance is two dimensional.

Accomplishment Description

The primary instability leads to the growth of T-S waves and a streamwise almost periodic modulation of the flow. We study the linear stability of this flow with respect to spanwise periodic 3D disturbance. Floquet theory gives as a solution to the stability equations, all various types of resonance. We consider the case of principle parametric resonance responsible for strong growth of subharmonics in low disturbance environment. Numerical results for F =60E-6 show that the local (at fixed R) effect of

compressibility on the secondary subharmonics may be stabilizing or destabilizing depending upon their spanwise wavenumbers, as well as the finite amplitude of the primary 2D wave. However, the overall effect of increasing Mach number is a reduction in the growth rates and amplification factors of the secondary subharmonics, almost with no change in the streamwise location where this instability sets in.

Publications and Presentations

"Secondary three-dimensional instability in compressible boundary layers," by N. M. El-Hady. To be presented at the Transonic Symposium, NASA Langely Research Center, April 19-21, 1988.

Future Plans

Instability and transition due to secondary instability in supersonic boundary layers is under investigation, where the primary instability is three dimensional or a second mode (two dimensional) at high Mach Numbers. A fully spectral code is under preparation to solve both the compressible primary and the compressible secondary instability problems.

III. BOUNDARY LAYERS ON SWEPT WINGS

Most theoretical and experimental work was performed using the Blasius boundary layer to investigate the instability mechanism that breakdown due to turbulence. On the other hand, little is known about the physical phenomena that leads to transition in cases like swept wings where the boundary layer is three-dimensional. In this situation, the boundary-layer profile consists of a streamwise velocity component in the direction of the external inviscid flow and a crossflow velocity component normal to it along the wing surface. Due to that, different types of instability modes may exist and different possible interactions may occur between these modes resulting in

stability characteristics that is much different from what linear theory would suggest.

The resonant interaction of three waves is considered one of the mechanisms that play an important role in determining the nonlinear characteristics of the development of disturbances, leading to transition. Such resonance occurs whenever the real wavenumbers k and frequencies ω satisfy the conditions

$$k_1 \pm k_2 \pm k_3 = 0 \quad , \quad \omega_1 \pm \omega_2 \pm \omega_3 = 0$$

with corresponding signs being taken.

In Blasius boundary layer, there usually exist triads comprising of two-dimensional wave propagating in the flow direction and two-obliquely propagating plane waves. However, in three-dimensional boundary layers, as on a swept wing, the triad comprises of three resonantly interacting 3D waves that may propagate in different directions. Because 3D boundary layers are usually rich in instability modes, one expects the possible evolution of different triads with different interacting modes that resonate. This will lead to a rapid growth of their amplitudes, leaving users of the e^n transition criterion in great doubt in such cases.

Research Objective

We investigate the evolution of resonant triads in three-dimensional boundary layers. The triads investigated comprise of different instability modes, stationary crossflow (CF), traveling crossflow, vertical vorticity (VV), and Tollmien-Schlishting (TS) modes. The mean flow used in the calculations is the boundary layer on a modern LFC transonic 23 swept wing.

In our analysis the growth of the boundary layer is taken into account assuming that it is of the same order as the nonlinear effects.

Accomplishment Description

Our calculations showed that the development of many triads, whose components can, in principle, take part in several resonant interactions at once, occurs in three-dimensional flows of boundary-layer type.

An important role in the nonlinear process is played by the initial spectrum of amplitude and phases of the triad components.

Due to the interaction of different instability modes, even if they are not strongly amplified, the classification concept suggested by Pfenninger for the stability problem into independent modes is no longer valid.

Nonparallel flow effects control the initial development of the disturbance triad components while the disturbance amplitude is sufficiently small. As the amplitudes increase, nonlinear effects control their subsequent spatial development.

Publications and Presentations

"Evolution of resonant wave triads in three-dimensional boundary layers," by N. M. El-Hady. AIAA Paper No. 88-0405. Presented at the AIAA 26th Aerospace Sciences Meeting, Reno, Nevada, January 11-14, 1988.

Future Plans

Introducing the effect of compressibility of the flow on the evolution of the resonant triads is under progress. Also the effect of the boundary layer control on the wave interaction is planned for future study.